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The dynamical core of the Aeolus 1.0 statistical-dynamical atmosphere model: Validation and parameter optimization

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Abstract

© Author(s) 2018. We present and validate a set of equations for representing the atmosphere's large-scale general circulation in an Earth system model of intermediate complexity (EMIC). These dynamical equations have been implemented in Aeolus 1.0, which is a statistical-dynamical atmosphere model (SDAM) and includes radiative transfer and cloud modules (Coumou et al., 2011; Eliseev et al., 2013). The statistical dynamical approach is computationally efficient and thus enables us to perform climate simulations at multimillennia timescales, which is a prime aim of our model development. Further, this computational efficiency enables us to scan large and high-dimensional parameter space to tune the model parameters, e.g., for sensitivity studies.

Here, we present novel equations for the large-scale zonal-mean wind as well as those for planetary waves. Together with synoptic parameterization (as presented by Coumou et al., 2011), these form the mathematical description of the dynamical core of Aeolus 1.0.

We optimize the dynamical core parameter values by tuning all relevant dynamical fields to ERA-Interim reanalysis data (1983-2009) forcing the dynamical core with prescribed surface temperature, surface humidity and cumulus cloud fraction. We test the model's performance in reproducing the seasonal cycle and the influence of the El Niño-Southern Oscillation (ENSO). We use a simulated annealing optimization algorithm, which approximates the global minimum of a high-dimensional function.

With non-tuned parameter values, the model performs reasonably in terms of its representation of zonal-mean circulation, planetary waves and storm tracks. The simulated annealing optimization improves in particular the model's representation of the Northern Hemisphere jet stream and storm tracks as well as the Hadley circulation.

The regions of high azonal wind velocities (planetary waves) are accurately captured for all validation experiments. The zonal-mean zonal wind and the integrated lower troposphere mass flux show good results in particular in the Northern Hemisphere. In the Southern Hemisphere, the model tends to produce too-weak zonal-mean zonal winds and a too-narrow Hadley circulation. We discuss possible reasons for these model biases as well as planned future model improvements and applications.

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References

[1] Berger, A., Fichefet, T., Gallée, H., Tricot, C., and van Ypersele, J. P.: Entering the glaciation with a 2-D coupled climate model, Quaternary Sci. Rev., 11, 481-493, https://doi.org/10.1016/0277-3791(92)90028-7, 1992.

[2] Claussen, M., Mysak, L., Weaver, A., Crucifix, M., Fichefet, T., Loutre, M. F., Weber, S., Alcamo, J., Alexeev, V., Berger, A., Calov, R., Ganopolski, A., Goosse, H., Lohmann, G., Lunkeit, F., Mokhov, I., Petoukhov, V., Stone, P., andWang, Z.: Earth system models of intermediate complexity: Closing the gap in the spectrum of climate system models, Clim. Dynam., 18, 579-586, https://doi.org/10.1007/s00382-001-0200-1, 2002.

[3] Coumou, D., Petoukhov, V., and Eliseev, A. V.: Three-dimensional parameterizations of the synoptic scale kinetic energy and momentum flux in the Earth's atmosphere, Nonlin. Processes Geophys., 18, 807-827, https://doi.org/10.5194/npg-18-807-2011, 2011.

[4] Dee, D. P., Uppala, S. M., Simmons, A. J., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., Balmaseda, M. A., Balsamo, G., Bauer, P., Bechtold, P., Beljaars, A. C. M., van de Berg, L., Bidlot, J., Bormann, N., Delsol, C., Dragani, R., Fuentes, M., Geer, A. J., Haimberger, L., Healy, S. B., Hersbach, H., Hólm, E. V., Isaksen, L., Kållberg, P., Köhler, M., Matricardi, M., Mcnally, A. P., Monge-Sanz, B. M., Morcrette, J. J., Park, B. K., Peubey, C., de Rosnay, P., Tavolato, C., Thépaut, J. N., and Vitart, F.: The ERA-Interim reanalysis: Configuration and performance of the data assimilation system, Q. J. Roy. Meteor. Soc., 137, 553-597, https://doi.org/10.1002/qj.828, 2011.

[5] Dobrovolski, S. G.: Stochastic Climate Theory, Springer-Verlag Berlin Heidelberg, 2000.

[6] Ehlers, E. and Krafft, T.: Understanding the Earth System: Compartments, Processes and Interactions, Springer-Verlag, Berlin, Heidelberg, 2001.

[7] Eliseev, A. V., Coumou, D., Chernokulsky, A. V., Petoukhov, V., and Petri, S.: Scheme for calculation of multi-layer cloudiness and precipitation for climate models of intermediate complexity, Geosci. Model Dev., 6, 1745-1765, https://doi.org/10.5194/gmd-6-1745-2013, 2013.

[8] Eliseev, A. V., Mokhov, I. I., and Chernokulsky, A. V.: An ensemble approach to simulate CO2 emissions from natural fires, Biogeosciences, 11, 3205-3223, https://doi.org/10.5194/bg-11-3205-2014, 2014a.

[9] Eliseev, A. V., Demchenko, P. F., Arzhanov, M. M., and Mokhov, I. I.: Transient hysteresis of near-surface permafrost response to external forcing, Clim. Dynam., 42, 1203-1215, https://doi.org/10.1007/s00382-01--1672-5, 2014b.

[10] Flechsig, M., Böhm, U., Nocke, T., and Rachimow, C.: The Multi-Run Simulation Environment SimEnv, available at: https://www.pik-potsdam.de/research/ transdisciplinary-concepts-and-methods/tools/simenv/ (last access: 26 January 2018), 2013.

[11] Fraedrich, K. and Böttger, H.: A Wavenumber-Frequency Analysis of the 500 mb Geopotential at 50 N, J. Atmos. Sci., 35, 745-750, https://doi.org/10.1175/1520-0469(1978)0350745:AWFAOT2.0.CO;2, 1978.

[12] Ganopolski, A., Petoukhov, V., Rahmstorf, S., Brovkin, V., Claussen, M., Eliseev, A. V., and Kubatzki, C.: Climber-2: A climate system model of intermediate complexity. Part II: Model sensitivity, Clim. Dynam., 17, 735-751, https://doi.org/10.1007/s003820000144, 2001.

[13] Harvey, L. D. D.: Milankovitch Forcing, Vegetation Feedback, and North Atlantic Deep-Water Formation, J. Climate, 2, 800-815, 1989.

[14] Holland, M., Bitz, C., Eby, M., and Weaver, A.: The Role of Ice-Ocean Interactions in the Variability of the North Atlantic Thermohaline Circulation, J. Climate, 14, 656-675, https://doi.org/10.1175/1520-0442(2001)0140656:TROIOI2.0.CO;2, 2001.

[15] Huang, B., Thorne, P. W., Smith, T. M., Liu, W., Lawrimore, J., Banzon, V. F., Zhang, H.-M., Peterson, T. C., and Menne, M.: Further Exploring and Quantifying Uncertainties for Extended Reconstructed Sea Surface Temperature (ERSST) Version 4 (v4), J. Climate, 29, 3119-3142, https://doi.org/10.1175/JCLI-D-15-0430.1, 2016.

[16] Imkeller, P. and von Storch, J.-S.: Stochastic Climate Models, Birkhäuser, 2012.

[17] Ingber, L.: Adaptive simulated annealing (ASA): Lessons learned, Control Cybern., 25, 32-54, 1996.

[18] Jablonowski, C., Oehmke, R. C., and Stout, Q. F.: Block-structured adaptive meshes and reduced grids for atmospheric general circulation models, Philos. T. Roy. Soc. A, 367, 4497-522, https://doi.org/10.1098/rsta.2009.0150, 2009.

[19] Kirkpatrick, S.: Optimization by simulated annealing: Quantitative studies, J. Stat. Phys., 34, 975-986, https://doi.org/10.1007/BF01009452, 1984.

[20] Knutti, R., Stocker, T. F., Joos, F., and Plattner, G.-K.: Constraints on radiative forcing and future climate change from observations and climate model ensembles, Nature, 416, 719-723, https://doi.org/10.1038/416719a, 2002.

[21] Latif, M.: Dynamics of interdecadal variability in coupled ocean-atmosphere models, J. Climate, 11, 602-624, https://doi.org/10.1175/1520-0442(1998)0110602:DOIVIC2.0.CO;2, 1998.

[22] McGuffie, K. and Henderson-Sellers, A.: A Climate Modelling Primer, 3rd Edn., J. Wiley and Sons, 2005.

[23] Montoya, M., Griesel, A., Levermann, A., Mignot, J., Hofmann, M., Ganopolski, A., and Rahmstorf, S.: The earth system model of intermediate complexity CLIMBER-3alpha. Part I: Description and performance for present-day conditions, Clim. Dynam., 25, 237-263, https://doi.org/10.1007/s00382-005-0044-1, 2005.

[24] Petoukhov, V., Ganopolski, A., Brovkin, V., Claussen, M., Eliseev, A. V., Kubatzki, C., and Rahmstorf, S.: CLIMBER 2: a climate system model of intermediate complexity. Part I: model description and performance for present climate, Clim. Dynam., 16, 1-17, https://doi.org/10.1007/PL00007919, 2000.

[25] Polyakov, I. V., Alekseev, G. V., Bekryaev, R. V., Bhatt, U. S., Colony, R., Johnson, M. A., Karklin, V. P., Walsh, D., and Yulin, A. V.: Long-term ice variability in Arctic marginal seas, J. Climate, 16, 2078-2085, https://doi.org/10.1175/1520-0442(2003)0162078:LIVIAM2.0.CO;2, 2003.

[26] Rossow, W. B. and Schiffer, R. A.: Advances in Understandig Clouds from ISCCP, B. Am. Meteorol. Soc., 80, 2261-2287, https://doi.org/10.1175/1520-0477(1999)0802261:AIUCFI2.0.CO;2, 1999.

[27] Saltzman, B.: A Survey of Statistical-Dynamical Models of the Terrestrial Climate, Adv. Geophys., 20, 183-304, https://doi.org/10.1016/S0065-2687(08)60324-6, 1978.

[28] Schmittner, A. and Stocker, T. F.: The stability of the thermohaline circulation in global warming experiments, J. Climate, 12, 1117-1133, https://doi.org/10.1175/1520-0442(1999)0121117:TSOTTC2.0.CO;2, 1999.

[29] Taylor, K. E.: Summarizing multiple aspects of model performance in a Single Diagram, J. Geophys. Res., 106, 7183-7192, https://doi.org/10.1029/2000JD900719, 2001.

[30] Xiao, X., Kicklighter, D. W., Melilo, J. M., McGuire, A. D., Stone, P. H., and Sokolov, A. P.: Linking a global terrestrial biogeochemcal model and a 2-dimensional climate model: implications for the global carbon budget, Tellus, 49B, 18-37, 1997.